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Coral recruitment and potential recovery of eutrophied and blast fishing impacted reefs in Spermonde Archipelago, Indonesia

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ABSTRACT

Coral recruitment was assessed in highly diverse and economically important Spermonde Archipelago, a reef system subjected to land-based sources of siltation/pollution and destructive fishing, over a period of 2 years. Recruitment on settlement tiles reached up to 705 spat m^{-2} yr^{-1} and was strongest in the dry season (July–October), except off-shore, where larvae settled earlier. Pocilloporidae dominated near-shore, while a more diverse community of Acroporidae, Poritidae and others settled in the less polluted mid-shelf and off-shore reefs. Non-coral fouling community appeared to hardly influence initial coral settlement on the tiles, although, this does not necessarily infer low coral post-settlement mortality, which may be enhanced at the near- and off-shore reefs as indicated by increased abundances of potential space competitors on natural substrate. Blast fishing showed no local reduction in coral recruitment and live hard coral cover increased in oligotrophic reefs, indicating potential for coral recovery, if managed effectively.

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1. Introduction

Recruitment is a key factor in the recovery of coral communities after disturbance, e.g. mortalities following mass bleaching events (Tamelander, 2002), storms (Connell et al., 1997; Coles and Brown, 2007) or tsunamis (Sawall et al., 2010). The assessment of coral recruitment patterns is therefore of high importance for coral reef management (Connell et al., 1997; Glassom et al., 2004; Fox, 2004). Recruitment patterns are known to be influenced by a wide range of factors, inter alia fecundity and spawning of the adults, fertilization success of the gametes, dispersal and survival of the larvae, settlement, metamorphosis and post-settlement survival, which are further influenced by a variety of extrinsic factors.

Gamete development and spawning are initiated by certain environmental conditions, hence spawning is often synchronized, triggered by the calm season (van Woesik, 2010), increasing temperature (Shlesinger and Loya, 1985; Gleason, 1996; Guest et al., 2005) and/or by a particular moon phase (Richmond and Hunter, 1990). One of the advantages of spawning during the calm season, which usually coincides with low precipitation, low river run-off and low nutrient supply to coastal waters, may be in the lower abundance of space competitors that are competitively superior in nutrient-enriched waters (algae, fast-growing ascidians, barnacles and other opportunistic fouling organisms; Birkeland, 1977; Glassom et al., 2004). Larval dispersal depends on the competency period of the larvae and the prevailing small (within reef) and large-scale currents (between reefs) (Sammarco and Andrews, 1989; Black et al., 1990) and larvae settlement and metamorphosis depend on the availability and suitability of substrate, which is supportive if heterogeneous, non-moving and biologically preconditioned (Fox et al., 2003; Webster et al., 2004; Petersen et al., 2005; Sawall et al., 2010). After metamorphosis and initial growth, survival may further dependent on water quality, light environment and abundance of potential space competitors and predators (Birkeland, 1977; Abelson et al., 2005; Ferse, 2008). Hence, initial larval supply does not necessarily need to result in high recruitment success, and coral recruitment patterns can vary substantially at various spatial scales, leading to considerable fine- (within reef) and mesoscale (near- vs. off-shore) patchiness.

Anthropogenic impacts may have significant negative effects on natural recruitment patterns in corals (Tomascik, 1991; Abelson et al., 2005). Eutrophication, pollution and sedimentation were found to hamper gamete production, alter the timing of spawning and decrease the fertilization success (Gilmour, 1999; Loya et al., 2004). They were found to slow the development and metamorphosis of the larvae and decrease the survival of the coral recruits (Gilmour, 1999; Hughes and Connell, 1999; Abelson et al., 2005). Eutrophication is also known to foster the growth of potential space competitors of coral recruits (Tomascik, 1991; Dunstan and

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Johnson, 1998; Abelson et al., 2005), toxic cyanobacteria or macroalgae inhibiting coral larvae settlement (Kuffner and Paul, 2004). Sedimentation is known to hamper larvae settlement and to smother coral recruits (Hodgson, 1990). Another common human impact on coral reefs is overfishing and deleterious fishing practices such as blast and cyanide fishing. Overfishing could lead to a significant decimation of grazers, which control e.g. algae growth, hence controlling potential space competitor for coral recruits (Hughes and Connell, 1999). Furthermore, reef destruction through blast fishing was shown to increase the proportion and spatial extent of coral rubble, which because of its low resistance to physical dislodgement by waves and currents may provide a killing field for coral spat (Harrison and Wallace, 1990; Fox et al., 2003).

The Spermonde Archipelago in SW Sulawesi is one of the most diverse but also one of the most endangered coral reef regions of the world, located in the center of the Coral Triangle. The archipelago harbors diverse coral reefs but also supports an important part of the reef fishery in Indonesia for a growing coastal population (Pet-Soede et al., 1999). As a result, the archipelago is subjected to the combined impacts of destructive fishing (blast and cyanide fishing), overfishing and land run-off (eutrophication, pollution and sedimentation), which have collectively taken their toll on reef structure and function (Edinger et al., 1998; Pet-Soede et al., 1999).

Although Spermonde is one of the best studied reef systems in Indonesia, with detailed studies on reef distribution and biodiversity (e.g., Moll, 1983; Renema and Troelstra, 2001; Cleary et al., 2005), population dynamics (e.g., Knittweis et al., 2009) and coral physiology (Sawall et al., 2011), so far nothing is known about coral recruitment, in spite of reef monitoring and management activities over many years (e.g., COREMAP).

The aim of this study was to assess early recruitment patterns as a function of seasonality, abundance of potential competitors, and occurrence of anthropogenic stressors (eutrophication and localized blast fishing). This is expected to elucidate the dynamics, resilience and recovery potential of corals in one of the most diverse but also one of the most exploited coral reef regions worldwide.

2. Material and methods

2.1. Study sites

The study was conducted in the Spermonde Archipelago, SW-Sulawesi, Indonesia, featuring ~100 coral-fringed small islands scattered across a 40 km wide carbonate shelf (Fig. 1). Most reefs are well developed in the south, west and north faces of the island, with conspicuous reef gaps on the sandy steeper areas of the eastern sides (Moll, 1983). The shelf depth ranges from 10 m (near-shore) to 40 m (off-shore). The predominant current is consistent with the throughflow in the Makassar Strait directed from N to S year around (Storm, 1989). The near-shore reefs which are subjected to the run-off of rivers north and south of the city of Makassar carrying untreated waste water and industrial pollution from the 1.5 million inhabitants along with agricultural run-off feature only low coral cover and diversity (Edinger et al., 1998; Renema and Troelstra, 2001). The near mid-shelf reefs are still affected by the land run-off during the wet season (November to February), but also by local waste water discharge in some of the populated islands (Edinger et al., 1998; Renema and Troelstra, 2001). The remote mid-shelf and off-shore reefs near the shelf edge are mainly exposed to oligotrophic waters, with oceanic conditions and seasonal upwelling from Makassar Strait at the margins (Ilahude, 1978).

Seasonality is characterized by the wet NW-monsoon from November to February (*wet*, in the following), a transition period from wet to dry season between March and June (*trans*) and the

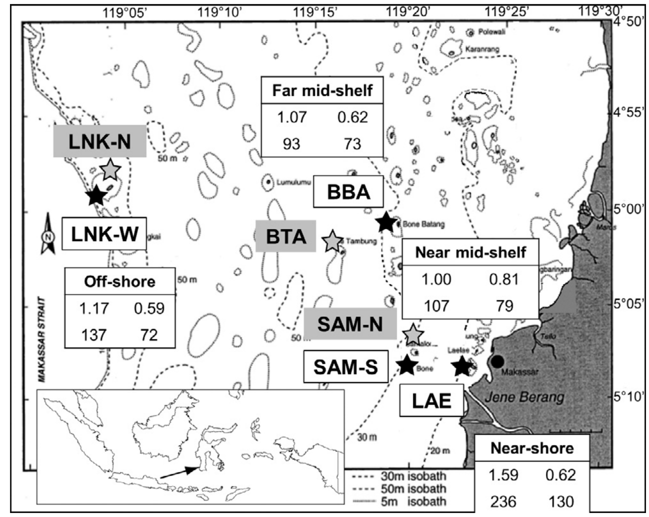

Fig. 1. Map of Spermonde Archipelago with the high (grey) and low (black) blast fishing impacted study sites: near-shore Lae Lae (LAE), near mid-shelf Samalona South (SAM-S) and Samalona North (SAM-N), far mid-shelf Bonebatang (BBA) and Bonetambung (BTA), off-shore Lanyukan West (LNK-W) and Lanyukan North (LNK-N). Parameters of water quality in tables: concentration [$\mu g\ l^{-1}$] of chlorophyll *a* (upper values) in February (left) and June (right), particulate organic carbon (lower values) in February (left) and June (right). Standard deviation for chlorophyll *a* between 0.04 and 0.33, and for particulate organic carbon between 2 and 20 (Sawall et al., 2012).

dry SE-monsoon from July to October (*dry*). Rainfall peaks in January with about 730 mm $month^{-1}$ and is lowest in August with 15 mm $month^{-1}$ (average data for 1961–1990, World Meteorological Organization, Geneva, Switzerland). Destructive fishing is common in Spermonde. Blast fishing leaves scars of coral rubble craters, which are consequently overgrown by macroalgae in some areas (Pet-Soede and Erdmann, 1998, pers. observ.). Reefs were classified as highly impacted with regard to blast fishing, if craters of coral rubble with a size of 5–15 m in diameter were evident and if those contributed with a minimum of 30% to the benthic cover. Seven study sites were chosen along a cross-shelf transect and classified into four different shelf zones distinguished by distance to shore and associated degree of eutrophication based on chlorophyll *a* and particulate organic carbon concentrations in the water (Fig. 1): (1) Near-shore (Lae Lae – LAE), (2) near mid-shelf (Samalona South – SAM-S, Samalona North – SAM-N) (3) far mid-shelf (Bonebatang – BBA, Bonetambung – BTA) and (4) off-shore (Lanyukan West – LNK-W, Lanyukan North – LNK-N). Each zone included a low and highly impacted reef by blast fishing, except for near-shore with a low impacted reef only (Fig. 1).

2.2. Characterization of the benthic community

Permanent line intercept transects (English et al., 1997) were conducted in order to assess the benthic community structure in November 2007, 2008 and 2009. A measuring tape was laid out over 60 m along the reef edge in 3 m depth and the underlying substrate was recorded to the nearest cm, always by the same investigator (YS). The following substrate categories were distinguished: live hard coral, dead coral (>15 cm), coral rubble (<15 cm), sand, macroalgae and others. The latter included soft corals, sponges, anemones, ascidians, hydrozoans and bivalves. The percentage contribution of each category was calculated.

2.3. Coral recruitment

Coral recruitment was monitored over 2 years from November 2007 until October 2009 on settlement tiles deployed at all 7 reef

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